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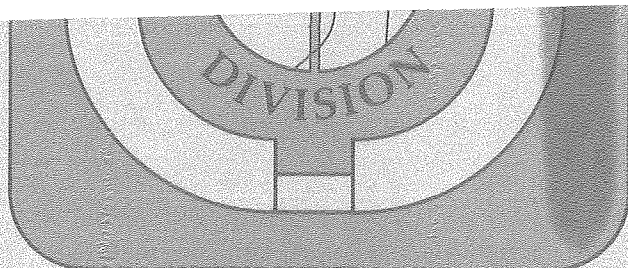
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The Quasi-Elastic Component in High-Energy Nuclear Collisions

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Abstract: The various definitions of the quasi-elastic component used in the current literature are discussed and interrelated. By use of the rows-on-rows model, it is demonstrated that the direct part of a recent two-component model approximates quite well the single-collision contribution to the one-nucleon inclusive cross section.

The reaction mechanisms acting in high-energy nuclear collisions have been the subject of intensive studies in recent years. Although purely thermal models (e.g., fireball¹⁾ and firestreak²⁾) have been quite successful in explaining early measurements¹⁾ of inclusive spectra, recent, more accurate measurements³⁻⁵⁾ at forward angles indicate the presence of a strong quasi-elastic component. Simplified multiple-collision models (e.g., rows-on-rows^{6,7)}, transport theory^{8,9)}, micro-canonical¹⁰⁾, and the two-component model direct-plus-thermal¹¹⁾)

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contain the quasi-elastic scattering mechanism in one way or another. The discussion of a nonequilibrated component in the inclusive spectra of high-energy nucleons has been carried to the extreme in ref. ¹²⁾, where it was assumed that the knock-out mechanism (i.e., a "cold" projectile nucleon collides with a "cold" target nucleon and both subsequently leave the interaction region) is the dominant reaction mechanism at forward angles. Meanwhile, it has become clear, however, that such a knock-out process has a quite small cross section, if properly normalized, as particularly emphasized in ref. ¹³⁾. By contrast, the properly weighted single-collision process contributes significantly, as has been shown in refs. ^{8,11)}. In the single-collision mechanism the observed nucleon suffers only one collision, while its collision partner may have undergone previous scatterings. Guided by experiment, it was assumed in refs. ^{8,11)} that it is a reasonable approximation to replace the momentum-space part of the single-collision contribution by the knock-out distribution. Let us, as in ref. ¹¹⁾, call the so approximated single-collision contribution the direct component. It is the aim of this note to phrase the notions of a "knock-out", a "single collision", and a "direct" component in a quantitative way and, in particular, to compare the direct and the single-collision components.

The tool for our study is the rows-on-rows model^{6,7)}. In this model, the one-particle inclusive invariant cross section is an incoherent sum of multiple-scattering contributions,

$$E \frac{d\sigma}{d\vec{p}} = \sum_{k=1}^{\infty} E \frac{d\sigma^{(k)}}{d\vec{p}} \quad (1)$$

The contribution from nucleons which have suffered exactly k collisions can be written as

$$E \frac{d\sigma^{(k)}}{d\vec{p}} = \sum_M \sigma_{AB}(M, k) \sum_{m=1}^M W_{mk}^A(\vec{p}) + \sum_N \sigma_{AB}(k, N) \sum_{n=1}^N W_{kn}^B(\vec{p}) \quad (2)$$

Here, the indices A and B refer to the projectile and target, respectively.

The quantity $\sigma_{AB}(m, n)$ is the cross section for the scattering of a row consisting of m projectile nucleons with a row consisting of n target nucleons. The spectral functions $\sum_{m=1}^M W_{mk}^A$ and $\sum_{n=1}^N W_{kn}^B$ are normalized to M and N , respectively. To bring out the relationship to other models, like those of refs. ^{8,14}, it is useful to define functions P_{Mk}^A and P_{kN}^B by

$$\sum_{m=1}^M W_{mk}^A(\vec{p}) = M P_{Mk}^A(\vec{p}) \quad (3)$$

$$\sum_{n=1}^N W_{kn}^B(\vec{p}) = N P_{kN}^B(\vec{p})$$

which are normalized to unity. Eq. (2) then becomes

$$E \frac{d\sigma^{(k)}}{d\vec{p}} = \sum_M M \sigma_{AB}(M, k) P_{Mk}^A(\vec{p}) + \sum_N N \sigma_{AB}(k, N) P_{kN}^B(\vec{p}) \quad (4)$$

In the rows-on-rows model, the cross sections $\sigma_{AB}(m, n)$ are calculated in the eikonal approximation. From their explicit form (cf, e.g., ref. ⁷),

one easily derives the sum rules

$$\sum_M M \sigma_{AB}(M, k) = A \sigma_B(k) \quad (5)$$

$$\sum_N N \sigma_{AB}(k, N) = B \sigma_A(k)$$

with

$$\sigma_A(k) = \frac{1}{k!} \int d\vec{s}' [\sigma_{NN}^{\text{tot}} \tilde{\rho}_A(\vec{s}')]^k e^{-\sigma_{NN}^{\text{tot}} \tilde{\rho}_A(\vec{s}')} \quad (6)$$

and analogously for $\sigma_B(k)$. Here σ_{NN}^{tot} is the free nucleon-nucleon total cross section, and $\tilde{\rho}_A$ is the z-integrated nucleon density of nucleus A (normalized to the total nucleon number also denoted by A). It follows that the contribution to the total inclusive cross section from nucleons which have collided k times is given by

$$\sigma^{(k)} = \int E \frac{d\sigma^{(k)}}{d\vec{p}'} \frac{d\vec{p}'}{E} = A \sigma_B(k) + B \sigma_A(k) \quad (7)$$

A recent calculation¹⁴⁾ of these quantities in a full three-dimensional cascade model yields results which are nearly identical to those of the rows-on-rows model given in ref. ⁷⁾. This fact lends additional support to the utility of the eikonal approximation.

In the following, we focus on the single-collision term of eq. (4) and its approximations. The direct term in the transport model⁸⁾ and the two-component model¹¹⁾ is obtained from (4) and (5) by approximating P_{M1}^A by P_{11}^A and P_{1N}^B by P_{11}^B , i.e.,

$$E \frac{d\sigma^{direct}}{d\vec{p}} = A \sigma_B(1) P_{11}^A(\vec{p}) + B \sigma_A(1) P_{11}^B(\vec{p}) \quad (8)$$

The knock-out component is obviously given by

$$E \frac{d\sigma^{ko}}{d\vec{p}} = \sigma_{AB}(1,1) [P_{11}^A(\vec{p}) + P_{11}^B(\vec{p})] \quad (9)$$

One finds that $\sigma_{AB}(1,1) \ll A\sigma_B(1), B\sigma_A(1)$, (when $A, B \gg 1$, as is usually the case). Therefore, the pure knock-out process is only a small fraction of the total direct component. For the symmetric system Ne on NaF at 800 MeV/N, which we shall use as an illustration, one finds typically $d\sigma^{ko}/d\sigma^{direct} \approx 0.2$. This is the reason why the knock-out component will not be visible in the inclusive cross section.

After having clarified the relation between the single-collision, the direct, and the knock-out components, it remains to be seen whether

$E \frac{d\sigma^{direct}}{d\vec{p}}$ is a good approximation to $E \frac{d\sigma^{''}}{d\vec{p}}$. To elucidate this question we have calculated the corresponding spectra in the rows-on-rows model⁷⁾,

using Saxon-Woods nuclear density distributions with the parameters specified in ref. ⁷⁾, gaussian momentum distributions with equivalent Fermi

momenta $P_F = 230$ MeV/c, a total nucleon-nucleon cross section $\sigma_{NN}^{tot} = 40$

mb, and differential cross sections $d\sigma/dt \sim \exp(t/2q^2)$ with $q = 350$

MeV/c. Figure 1 shows the results for 800 MeV/N Ne on NaF, under the

artificial assumption that only elastic nucleon-nucleon scattering occurs.

The inclusive nucleon spectra are shown in the mid-rapidity frame at angles $30^\circ, 60^\circ, 90^\circ$. Figure 2 shows the corresponding results when the

calculation more realistically includes the inelastic process leading to delta formation, and subsequent pion production (the N/Δ branching ratio

is taken as 0.35). In either case the correspondence between the

single-collision spectrum (solid curves) and the direct spectrum eq. (8) (dashed curves) is rather good over a wide kinematical range. (The agreement is better than a factor of two for proton energies between 50 MeV and 450 MeV.) The main reason for this striking result is that the leading corrections P_{21}^A and P_{12}^B are still rather similar to P_{11} , as can be inferred from the collision kinematics. Although the deviations are larger at the high-energy end, this is of little consequence since the multiple-scattering component of the nucleon inclusive cross section is dominant in this regime¹⁵⁾.

To summarize, we have elucidated the relation between the notions of a single, direct, and knock-out component in the nucleon inclusive cross section. A significant outcome of our investigation is the good agreement between the single-collision and the direct component over a wide kinematical region. Since the latter has a far simpler structure than the former, it permits an easy and fairly reliable estimate of the single-collision term. As a consequence of this, given the experimental inclusive cross section, it is relatively easy to disentangle single from multiple scattering contributions and study their competition in various kinematical regions. Such investigations are adding greatly to our general understanding of the reaction mechanism in high-energy nuclear collisions.

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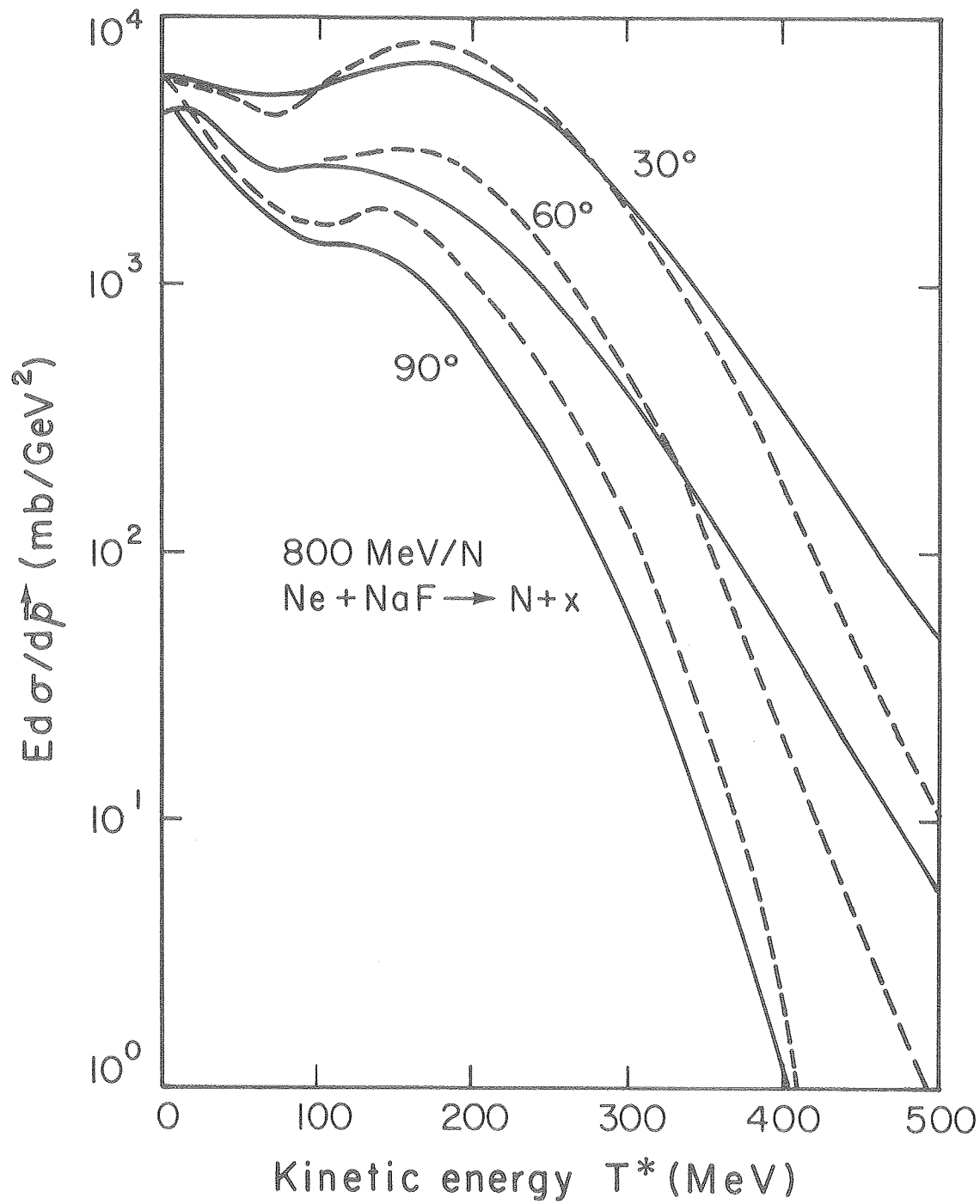
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Figure captions

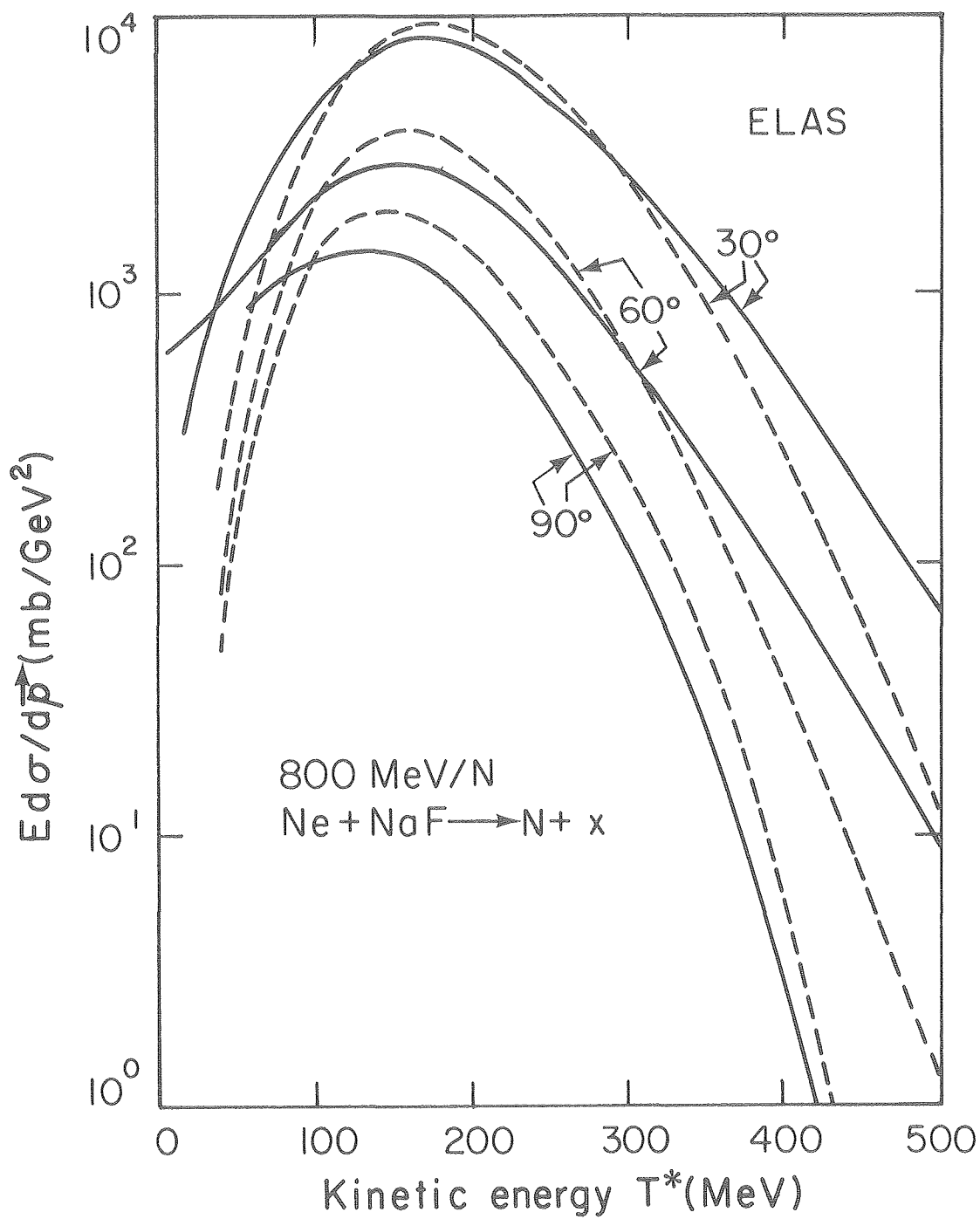
Fig. 1 The invariant nucleon spectra in the mid-rapidity frame for 800 MeV/N Ne on NaF, considering only elastic nucleon nucleon scattering. The solid curves indicate the single-scattering spectrum (eq. (4) with $k = 1$) while the dashed curves show the direct spectrum as given by eq. (8).

Fig. 2 Similar to fig. 1 but the cascade calculation includes the inelastic delta channel as in ref. ⁷⁾.



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Fig. 1



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Fig. 2